

“A Magnetic Survey of the Fortieth Parallel in North America between the Atlantic Ocean and the Great Salt Lake, Utah.” By T. E. THORPE, Ph.D., F.R.S. Received March 25: Read May 1, 1879.

A glance at the maps which accompany Sir Edward Sabine's “Contributions to Terrestrial Magnetism,” published at various times in the “Philosophical Transactions of the Royal Society,” is sufficient to show that considerable as is our knowledge of the magnetic history of our globe, there are still very large areas of the earth's surface about which we have practically no information. A remarkable instance of this fact is afforded by the case of the North American Continent, more especially by that portion belonging to the United States. Magnetic observations have been made, with more or less assiduity, at different places in the Eastern States, for many years past; but over the immense tract of country lying between the Mississippi and the Pacific Ocean—a tract comprising upwards of 200,000 square miles, there is only a single determination of one of the three magnetic elements indicated on Sir E. Sabine's maps, viz., a determination of declination at Salt Lake City. A series of observations was made some years since by United States officers along the Mexican frontier, and a similar series was carried out by the English and American officers employed on the North American Boundary Commission. But the latter observations, I believe, have not yet been published.

My attention was first drawn to this matter by my friend Mr. G. M. Whipple, the Superintendent of the Kew Observatory, in the course of some conversation respecting a journey to Western America which I contemplated making in order to observe the total solar eclipse of last July. As my station was to be in the State of Colorado, which is practically midway between the northern and southern boundaries along which the observations above referred to had been made, it seemed to Mr. Whipple advisable to seize the opportunity to add to our magnetical knowledge of the intervening area to the extent even of securing observations on a single spot only. Further consideration showed that the project might be extended with advantage, and accordingly I offered to make a complete series of observations of the three elements—dip, intensity, and declination, at such times and places as the circumstances of travel would allow. The Kew Committee kindly offered me the loan of the instruments which the Rev. S. J. Perry had employed in Kerguelen's Land and in other places on the occasion of the recent Transit of Venus Expedition; at the same time Professor Balfour Stewart generously undertook to use his influence with the Council of the Owens College to obtain for me the admirable magnetic equipment belonging to that institution. After

some experience with both sets of instruments, I decided to accept those belonging to the Owens College, partly because they were of more modern construction than the others, being furnished with certain contrivances and improved modes of adjustment, suggested by Dr. Stewart's extensive experience, which made them more convenient to use, whilst they materially added to the trustworthiness of their indications; and partly (which was of great importance) because the instrumental constants had been comparatively recently determined and verified by Mr. Whipple. The Owens College instruments consisted of a dip-circle by Dover, No. 6; a unifilar magnetometer by Elliott Brothers, No. 27; and a marine chronometer by Frodsham, No. 4066. I would here record my sense of obligation to Professor Stewart and the Council of the Owens College for the readiness with which they placed their instruments at my disposal. My thanks are also due to the Kew authorities for the loan of a couple of tripods. I am specially indebted to Mr. Whipple and to Mr. Figg, the Magnetic Assistant at the Kew Observatory, for instruction in the use of the instruments, for advice in the conduct of the observations, and for assistance in their subsequent reduction.

In addition to the ordinary magnetic instruments, I provided myself with an excellent 7-inch sextant by Casella, a couple of artificial horizons, some spare thermometers, an aneroid for altitudes up to 5,000 feet, and a hypsometric apparatus for greater elevations. The fortunate circumstance that I was accompanied by Dr. Schuster has added, in no small degree, to the completeness of the work; for that gentleman, being provided with one of Pistor and Martin's small prismatic circles, and being very expert in its use, kindly offered to take charge of the observations for time and latitude throughout the journey. It is in great measure due to this assistance that I have been able to develop the original intention into what may be considered as practically a magnetic survey of the fortieth parallel across the American Continent, that is to say, of the district which lies midway between the line of observations already run along the northern and southern boundaries of the United States territory.

The observations were begun at Kew, which was adopted as a base station, and were resumed on the other side of the Atlantic, at New Haven, Connecticut. Determinations were next made at La Junta in South Colorado, the eclipse station selected by Professor Asaph Hall, of the United States Naval Observatory; afterwards at Manitou, at the base of Pike's Peak; at Denver, and at Cheyenne in Wyoming. No further observations were made until we arrived at Salt Lake City, where, thanks to the kindness of President Taylor, we were permitted to make a complete series in an excellent spot in a garden to the side of the late President Young's house. The transit instrument, by Würdermann, of Washington, belonging to the Community, which is

mounted in the rear of the Tabernacle, was also placed at our disposal; and we had an opportunity of comparing our chronometers with an instrument (Dent, 2392) which is regularly rated from transit observations made by Mr. Anderson, of the President's Office. Our next station was Ogden, in Northern Utah, at the observatory directed by Lieutenant Wheeler, of the United States Engineers, and on the spot selected by the French astronomers for their observations of the recent Transit of Mercury. The observatory was then in charge of Professor Truman Safford, of Williams College, who also rated our chronometers and otherwise did all in his power to facilitate our work. The next stations were Green River in Wyoming, Grand Island in Nebraska, Council Bluffs in Iowa, Chicago, Allegheny, and Washington. Washington is one of the best observed stations in the States. Mr. Schott, of the United States Coast Survey Department, who is well known as a leading magnetician in America, has here made regular determinations in an observatory in the neighbourhood of the Capitol Hill for many years past, and these he has tabulated and discussed in various publications issued by the Coast Survey authorities. My object in selecting Washington was to obtain an independent check on the indications of my instruments. Mr. Schott was kind enough to allow me to set up my instruments in his observatory, and to afford me such assistance and information as I needed.

I learned that the Coast Survey Department is gradually accumulating data for a discussion of the magnetic history of the continent. It has already published a map of declination for 1870, from which it is evident that much has been done in the determination of this particular element since the date of Sir Edward Sabine's "Memoirs," more especially along the Pacific slope and in the regions to the west and south-west of the Great Salt Lake. As yet, however, no observations have been published relating to any of the districts west of the Mississippi that we visited.

The geographical positions of the several stations, their altitudes above the sea-level, the geological character of the district in which they are situated, together with such details of the exact sites as may be necessary for their identification, are given in Table I. For the greater part of the geological information I am indebted to my colleague, Professor A. H. Green; the rest I owe to the kindness of General Humphreys, Chief of the United States Engineers, who supplied me with the beautiful geological and topographical atlas accompanying Mr. Clarence King's Report of the Geological Exploration of the Fortieth Parallel.

I. *Dip.*

The dip circles at my disposal were Barrow, No. 23, and Dover, No. 6. The late Mr. Welsh had employed the former instrument in

Table I.

Station.	Altitude in feet above sea level.	Latitude. N.	Longitude (from Washington).	Geological Character.	Remarks.
New Haven, Connecticut	50	41° 18' 41"	h. m. s. 0 16 30 E.	Red sandstone, with intrusive trap	In Professor Silliman's garden. The New Haven and Northampton Railway runs N.N.W. to S.S.E. about 110 yards west of station.
La Junta, Colorado	4,190	37° 58' 55"	1 45 57.7 W.	.. ..	About 100 paces N.N.W. of Eclipse Station. Dry sandy soil.
Manitou, Colorado	6,300	38° 51' 55"	1 51 25.9 "	Limestone and red sandstone	In a grove to the S. of the Cliff House, near the Navajo Soda Spring, and on the edge of the Fontaine-qui-bouille.
Denver, Colorado	5,196	39° 45' 20"	1 51 46.1 "	Sands and clays	In Mrs. Craig's garden, to N.W. of town, between the Waterworks and Colorado Central Railway.
Cheyenne, Wyoming	6,075	41° 07' 46"	1 51 03.1 "	Fine marly sandstones, clays, conglomerates, and limestones	On plot of land between Court House and School House, $\frac{1}{4}$ mile to rear of railroad station.
Salt Lake City, Utah	4,340	40° 46' 04"	2 19 22.4 "	Gravels	On rising ground to the east of the President's house, between that and the White House-on-the-Hill, the residence of Mrs. M. A. Young.

Table I—*continued*.

Station.	Altitude in feet above sea level.	Latitude. N.	Longitude (from Washington).	Geological Character.	Remarks.
Ogden, Utah	4,374	41° 13' 09"	h. m. s. 2 19 47·5 W.	Gravels	At Observatory near the thermometer station, about 70 feet N.W. of dome.
Green River, Wyoming ..	6,117	41 31 38	2 9 40·2 "	Calcareous shales	In rear of town, to the west of the school house, and directly opposite the front of the Court House, 542 feet N.N.E. of station of U.S. Engineers.
Grand Island, Nebraska..	1,850	40 55 24	1 24 57·7 "	.. ..	In Mr. Michelson's garden, 655 feet S.S.E. from railroad station U.P.R.R. Dry sandy soil.
Council Bluffs, Iowa ..	1,320	41 15 17	1 15 17·0 "	Limestone, with beds of shale and grit	On the edge of large field of sunflowers, 900 feet N. of the Union Pacific Depôt.
Chicago, Illinois	613	41 50 01	0 42 14·7 "	Probably limestone	In grounds of Chicago University, 174 feet to the north of the western edge of Observatory tower, and 243 feet from door of Transit House in rear of University buildings.
Allegheny, Pennsylvania	1,145	40 27 36	0 11 50·6 "	Sandstones, shales, and coal	In grounds of the Observatory, about 35 feet due north of the dome.
Washington, D. C.	70	38 53 12	0 0 0	Gneiss	In Mr. Schott's Magnetic House on the Capitol Hill, 212, First Street, S.E.

his Magnetic Survey of Scotland in 1856-57: it had been carefully examined by Dr. Balfour Stewart for error of axle and evidence of local magnetism in the circle. (See "British Association Reports," Aberdeen, 1859.) After a number of trials with both circles, I decided to make use of the one belonging to Owens College (the Dover circle), principally for the reason that the method of lifting the needles in that instrument seemed to afford more concordant results than that adopted in the other. The Dover circle was provided with two needles of the ordinary form, each 3·5 inches long and 0·27 inch in maximum breadth.

In order to preserve them from rust during the sea-voyage, the needles were carefully wrapped in gutta-percha tissue and placed in a small box filled with soda-lime. This method of preservation was found to be perfectly efficacious: at no time during the journey was the slightest trace of oxidation discernible under the magnifying glass.

The mode of observing was that described by Mr. Welsh in the "Admiralty Manual of Scientific Inquiry," 3rd edition, 1859. Eight readings of the vertical needle gave the magnetic prime vertical. The circle was then turned so that the needle could oscillate in the magnetic meridian. Sets of readings were taken with the face of the circle first east and then west, the face of the needle being towards the face of the instrument; the needle was then reversed on its bearings and again read east and west: afterwards its polarity was reversed by stroking with the bar-magnets and both series of readings were repeated. The needle was raised and lowered several times between each set of readings; these were in all cases repeated, and if a difference of more than 3' was observed, a fresh set was taken.

A comparison, made at Kew, between the Dover circle and the instrument employed in the monthly observations regularly carried on at that observatory, afforded the following results:—

Kew, June 7, 1878. Time, 9.30 A.M. to 12.26 P.M.

	Needle 1.		Needle 2.		Mean.
Dover Circle	67 41·8 ..		67 44·1 ..		67 43·0
Kew Circle { 1st series..	67 43·8 ..		67 44·1 ..	}	67 44·2
{ 2nd ,, ..	67 44·7 ..		67 44·1 ..		

A second set of comparisons at Kew, made after the return from America, gave the following numbers:—

	Needle 1.		Needle 2.		Mean.
Dover Circle, Oct. 2, 1878	67 45·7 ..		67 41·6 ..		67 43·7
Kew Circle { Sept. 25, ,,	67 43·5 ..		67 43·4 ..	}	67 43·6
{ ,, 26, ,,	67 43·8 ..		67 43·8 ..		

These results are perfectly satisfactory, and show that the Dover circle is calculated to afford the true dip at the various stations along the line of survey. The results of the American observations are contained in Table II.

Table II.

Station.	Date. 1878.	Local time.		Needle No. 1.	Needle No. 2.	Mean.
		h. m.	h. m.			
New Haven ..	July 17	11 0	to 1 3	73 05.8	73 05.0	73 05.4
La Junta	" 25	9 55	" 1 25	66 01.3	66 03.2	66 02.3
Manitou	Aug. 4	11 8	" 4 39	66 58.5	66 59.9	66 59.2
Denver	" 8	10 27	" 12 6	67 31.2	67 34.3	67 32.8
Cheyenne	" 9	3 19	" 4 23	69 01.5	69 02.5	69 02.0
Salt Lake City.	" 14	10 13	" 12 55	67 01.9	67 02.6	67 02.3
Ogden	" 24	12 31	" 2 31	67 23.0	67 26.1	67 24.5
Green River ..	" 26	2 59	" 3 57	68 20.5	..	68 20.5
Grand Island .	" 28	3 52	" 5 24	70 19.1	70 16.2	70 17.7
Council Bluffs.	" 30	9 26	" 10 51	71 05.2	71 06.2	71 05.7
Chicago	Sept. 2	12 33	" 2 21	72 40.1	72 38.7	72 39.4
Allegheny	" 5	12 15	" 2 10	72 07.0	72 08.0	72 07.5
Washington ..	" 8	11 22	" 1 11	70 47.8	70 45.9	70 46.9

Only a single complete set of observations with needle 1 could be taken at Green River. This was just concluded when a sudden and violent wind-storm, which filled the air with dust and nearly upset the tripods, put an end to the work. In the absence of the requisite data it is scarcely possible to attempt to correct the foregoing numbers for secular variation, even if that should be thought necessary; the time occupied by the survey was hardly long enough to affect the results to any appreciable extent. We may, therefore, safely take 1878.7 as the epoch of all the observations.

Of the thirteen stations named in the foregoing table, New Haven, Washington, Allegheny, and Chicago alone would seem to afford data for a discussion of the yearly rate of change in the inclination; these four towns (if we may consider Pittsburg and Allegheny, which are merely separated by the Monongahela River, as practically identical) are the only ones included in the long list given by Sir Edward Sabine for the epoch 1842.5. (Contributions to Terrestrial Magnetism, No. XIII, "Philosophical Transactions," 1872.) The difference in dip at the four stations at the two epochs may be seen from the following table:—

Station.	Dip 1842.5.		Dip 1878.7.		Diff. of Epoch.		Diff. of Dip.
New Haven..	73 30	..	73 05.4	..	36.2 years	..	24.6
Washington	71 18	..	70 46.9	..	"	..	31.1
Pittsburg ..	72 40.5	..	72 07.5	..	"	..	33.0
Chicago	72 44.3	..	72 39.4	..	"	..	4.9

No certain conclusion, however, can be drawn from these numbers respecting the extent of the secular change in this element, since, as Mr. Schott's observations at Washington have shown, the dip at that place was on the increase at the epoch 1842·5, and attained a maximum about 1854·8. Doubtless a similar increase occurred at New Haven and Pittsburg (Allegheny) and probably a maximum was also reached at these places at about the same period. The result for Chicago seems exceptional; I am hardly inclined to regard it as due to an error in the determination of the dip at the epoch 1842·5, on account of the number and fairly concordant character of the observations, which were all made at about the time of the first epoch by different observers. These are—

Loomis 1841	72° 48'
Nicollet 1841	72° 46'
Younghusband 1842 ..	72° 39'

My own results agree perfectly among themselves: they were taken under favourable circumstances, and so far as I could learn from Professor Colbert, the Director of the Dearborn Observatory—there was nothing in the spot selected for the observations—an open space in the grounds of the University of Chicago—which could at all interfere with the proper direction of the needle. Whether Chicago is affected by any strong local disturbance I am unable to say: the geological character of the district affords no evidence on this point.

In an Appendix to the "United States Coast Survey Report for 1870," Mr. Schott has discussed the secular changes in the declination, dip, and intensity of the magnetic force at Washington. The observations of inclination, which extend over a period of nearly forty years, may be represented by the expression—

$$I = 71^{\circ} 33' 5'' - 0.000229 (t - 1855.0) - 0.000640 (t - 1855)^2 - 0.0000303 (t - 1855)^3,$$

which, as the accompanying comparisons show, gives results closely accordant with the observed values.

Date.	Observed Dip.	Computed Dip.	Difference.
1839.2	71° 29'	71° 30'	-0.01
1851.5	71° 32'	71° 33'	-0.01
1861.6	71° 30'	71° 30'	-0.00
1871.4	71° 00'	71° 03'	-0.03
1872.5	71° 00'	70° 97'	+0.03
1873.5	70° 97'	70° 92'	+0.05

This formula, although perfectly applicable between the intervals

for which it was originally calculated, no longer accords with the observations of the present epoch. On June 15, 1878, Mr. Schott found the magnetic dip, at his observatory, to be $70^{\circ}80'$: my own observations at the same place, three months later, made it $70^{\circ}78'$; the value calculated from the above formula is $70^{\circ}57'$, or $14'$ less than the mean of our observations, an amount far in excess of the error of the observation. It is not at all improbable, as indeed Mr. Schott has already remarked, that although on the whole the dip is decreasing at Washington there are subordinate periods of comparatively short duration during which an increase occurs, the former rate of diminution being afterwards re-established. Inequalities of the same kind, although by no means of the same extent, have also been traced in the observations of inclination made at Toronto and Kew by Sir Edward Sabine and Dr. Balfour Stewart (Sabine, "Phil. Trans., 1863;" Stewart, "Proc. Roy. Soc.," vol. xviii, 1870).

Intensity.

The horizontal component of the earth's magnetic force was determined by the method of vibrations and deflections in the manner described in the "Admiralty Manual of Scientific Inquiry," 3rd edition, 1869. By the aid of the deflections we obtain $\frac{m}{X}$, or the ratio between the magnetic moment of the magnet employed and the horizontal component; from the vibrations we find the product mX , whence either m or X may be obtained. The total force I is obtained by dividing X by the cosine of the observed dip; and from this we readily find the vertical component V from the formula:—

$$V^2 = I^2 - X^2.$$

The final results are stated in British and metrical units; one foot, one second of mean solar time, and one grain being the units of space, time, and mass in the one case; and one millimetre, one second of time and one milligramme being the units in the other. By dividing the latter values by 10, the corresponding values in C. G. S. are also obtained. The factor for converting the British to metric values is 0.46108.

The value of $\log \pi^2 K$ at 60° is 1.62832, as determined by Mr. Whipple, at Kew.

The induction coefficient μ is 0.0001615.

The correction for temperature t° to the adopted standard temperature 35°F. , is

$$0.0001383 (t^{\circ} - 35^{\circ}) + 0.00000607 (t^{\circ} - 35^{\circ}).$$

The correction for error of graduation of the brass deflection bar at 1 foot is -0.000135 foot and at 1.5 foot -0.00087 foot.

The times of vibration given in the table are, in all cases, obtained from the means of 14 observations of the time required by the magnet to make 100 vibrations : no correction has been applied for semi-arc of vibration which at the commencement of the observations was always below 50'; at two stations only, viz., at Salt Lake City and at Council Bluffs—where the rate of the chronometer exceeded 3 seconds, was it necessary to apply the correction $1 - \frac{s}{86400}$. The observed time of vibration has been also duly corrected for the torsion-force of the suspending thread. The angular value of 1 division of the scale of the vibration magnet is 2' 12'' : that of the deflection apparatus is 60''·5.

The mean value of P in the formula $\frac{m}{X} = \frac{m'}{X'} \left(1 - \frac{P}{r_0^2} \right)$ was -0·002357.

Tables III and IIIA contain the details of the several observations.

Table III.—Deflection Observations.

Station.	G. M. Time.	Distances of Centres of Magnets.	Tempe- rature.	Observed Deflection.	Log $\frac{m}{X}$.
	d. h. m.	foot.			
New Haven	July 17 11 14 A.M.	1·0	77°·7	16 42 26	9·16182
	11 58 "	1·3	78·0	7 30 55	9·16120
	" 18 4 48 P.M.	1·0	99·8	16 36 07·5	9·16136
	5 28 "	1·3	100·0	7 28 53	9·16146
La Junta	" 25 9 14 A.M.	1·0	93·0	12 03 34	9·02471
	9 54 "	1·3	93·6	5 27 51	9·02492
Manitou	Aug. 6 7 05 A.M.	1·0	86·4	12 33 47	9·04109
	7 46 "	1·3	86·0	5 40 40	9·04113
Denver	" 8 11 44 A.M.	1·0	87·7	12 45 52·5	9·04847
	12 14 "	1·3	87·9	5 46 52	9·04875
Salt Lake City ..	" 14 10 06 A.M.	1·0	94·9	12 39 57·5	9·04590
	10 42 "	1·3	94·4	5 44 13	9·04609
Ogden	" 24 11 16 A.M.	1·0	90·0	12 47 36	9·04967
	11 48 "	1·3	89·4	5 47 53·5	9·05021
Green River	" 26 5 39 P.M.	1·0	87·2	13 12 05·5	9·06278
	6 03 "	1·3	87·0	5 58 16	9·06263
Grand Island ..	" 28 8 59 A.M.	1·0	83·6	13 55 31	9·08518
	9 36 "	1·3	83·8	6 17 39·5	9·08513
Council Bluffs ..	" 30 5 30 A.M.	1·0	84·9	14 33 28	9·10420
	5 57 "	1·3	84·4	6 34 36	9·10416
Chicago.....	Sept. 2 8 50 A.M.	1·0	84·0	15 39 30	9·13500
	9 27 "	1·3	83·5	7 03 45	9·13490
Allegheny.....	" 5 8 09 "	1·0	78·4	15 25 41	9·12820
	8 40 "	1·3	79·0	6 57 56·5	9·12849
Washington	" 8 7 20 "	1·0	77·9	14 36 11	9·10483
	7 53 "	1·3	78·1	6 35 59	9·10505

Table IIIA.—Vibration Observations.

Station.	Date.	Temperature.	Time of one Vibration.	Log m X.	Value of m .
	d. h. m.		secs.		
New Haven	July 17 11 12 A.M.	75° 0	4·4424		
	11 24 "	74° 7	4·4450	0·33508	
	" 18 4 05 P.M.	95° 0	4·4573		0·5599
	4 17 "	95° 5	4·4539	0·33464	
La Junta	" 25 11 04 A.M.	100° 0	3·8162		
	11 14 "	98° 0	3·8162	0·46943	0·5587
Manitou	Aug. 6 6 15 A.M.	85° 0	3·8947		
	6 26 "	85° 7	3·8967	0·45025	0·5568
Denver	" 8 11 04 A.M.	98° 0	3·9296		
	11 15 "	97° 0	3·9300	0·44388	0·5575
Cheyenne	" 10 4 20 P.M.	72° 0	4·0230		
	4 31 "	72° 2	4·0229	0·42116	0·5570
Salt Lake City ..	" 14 11 12 A.M.	96° 0	3·9200		
	11 23 "	94° 8	3·9196	0·44560	
	" 15 5 05 P.M.	95° 0	3·9223		0·5566
	5 16 "	94° 5	3·9219	0·44499	
Ogden	" 24 10 43 A.M.	101° 5	3·9564		
	10 54 "	102° 0	3·9559	0·43809	0·5547
Green River	" 26 5 03 P.M.	87° 0	4·0034		
	5 14 "	86° 7	4·0030	0·42644	0·5553
Grand Island .	" 28 7 04 P.M.	95° 0	4·1087		
	7 15 "	91° 5	4·1087	0·40450	0·5557
Council Bluffs ..	" 30 3 03 P.M.	84° 0	4·2010		
	3 16 "	83° 7	4·2007	0·38439	0·5550
Chicago	Sept. 2 3 06 P.M.	88° 0	4·3550		
	3 18 "	89° 2	4·3549	0·35350	0·5548
Allegheny	" 5 4 39 P.M.	85° 5	4·3193		
	4 51 "	80° 0	4·3194	0·36013	0·5549
Washington	" 8 6 37 P.M.	78° 0	4·1997		
	6 49 "	77° 9	4·1996	0·38405	0·5552

The final results of the intensity observations are contained in Table IIIB.

Table III.B.—Magnetic Intensity.

	British Units.			Metric Units.		
	Horizontal Force.	Vertical Force.	Total Force.	Horizontal Force.	Vertical Force.	Total Force.
New Haven	3·8610	12·7001	13·2740	1·7802	5·8558	6·1204
La Junta.....	5·2761	11·8717	12·9913	2·4327	5·4738	5·9900
Manitou	5·0649	11·9245	12·9555	2·3353	5·4981	5·9735
Denver	4·9847	12·0619	13·0513	2·2983	5·5615	6·0177
Cheyenne	4·7348	12·3561	13·2322	2·1831	5·6972	6·1011
Salt Lake City ...	5·0061	11·8156	12·8324	2·3082	5·4479	5·9168
Ogden	4·9440	11·8821	12·8696	2·2796	5·4786	5·9339
Green River	4·8069	12·1048	13·0243	2·2164	5·5813	6·0052
Grand Island	4·5675	12·7531	13·5463	2·1060	5·8802	6·2459
Council Bluffs	4·3663	12·7493	13·4763	2·0132	5·8784	6·2137
Chicago	4·0671	13·0232	13·6435	1·8753	6·0047	6·2907
Allegheny	4·1294	12·8040	13·4534	1·9040	5·9037	6·2031
Washington	4·3608	12·5096	13·2479	2·0107	5·7679	6·1083

The following observations of horizontal force in absolute measure were made at Kew with the Owens College unifilar before and after the American observations.

June 7, 1878.—Deflection Observations.

G. M. T.	Distance of centre of magnets.	Temp.	Observed deflection.	Log $\frac{m}{X}$
h. m.	ft.	°	° ' "	
4 24 ..	1·0 ..	77·4 ..	16 29 18 ..	9·15621
5 02 ..	1·3 ..	77·4 ..	7 25 46 ..	9·15610

Vibration Observations.

G. M. T.	Temp.	Time of the vibration.	Log mX .
h. m.	°	sec.	
3 07	74·6	4·4231	0·33899
3 19	74·6	4·4230	

October 2, 1878.—Deflection Observations.

G. M. T.	Distance of centre of magnets.	Temp.	Observed deflection.	Log. $\frac{m}{X}$
h. m.	ft.	°	° ' "	
2 57 ..	1·0 ..	64·7 ..	16 21 33 ..	9·15174
3 24 ..	1·3 ..	64·7 ..	7 22 11 ..	9·15153

Vibration Observations.

G. M. T.	Temp.	Time of the vibration.	Log mX .
h. m.	°	sec.	
2 10	61·7	4·4399	0·33458
2 22	61·7	4·4400	

The magnetic moment of the magnet before and after the survey was as follows :—

		Mean.
Kew, June 7, 1878.—I.	0·5592	} ·5592
	II. 0·5592	
Oct. 2, 1878. I.	0·5535	} ·5535
	II. 0·5534	

The results of these observations compared with those of the Kew unifilar made at about the same period are as follows :—

		Horizontal force.	Diff.
Kew Unifilar.	May 27, 1878.	3·8958	
Owens College Unifilar . .	Sept. 7, „	$r=3·9030$	+0·0074
		$r^1=3·9034$	
Kew Unifilar	Sept. 24, 1878.	3·8962	
Owens College Unifilar . .	Oct. 2, „	$r=3·9032$	+0·0074
		$r^1=3·9041$	

Combining these results with the respective values for the inclination obtained by the several instruments, we have the following independent determinations of the magnetic intensity, in absolute measure, at Kew :—

		Horizontal.	Vertical.	Total.
Kew Instruments	May, 1878.	3·896	9·516	10·283
Owens College Instruments	June „	3·903	9·525	10·293
Kew Instruments	Sept. „	3·896	9·513	10·280
Owens College Instruments	Oct. „	3·904	9·531	10·299

Table IV shows the values in British units of the total force at such of the above stations as are mentioned in Sir Edward Sabine's "Contributions to Terrestrial Magnetism," No. XIII ("Philosophical Transactions, 1872,") at the two epochs 1842·5 and 1878·7.

Table IV.

		1842·5.		1878·7.		Diff.
Pittsburg ..	..	13·5	....	13·45	....	—·05
New Haven	..	13·37	....	13·27	....	—·10
Chicago ..	..	13·78	....	13·64	....	—·14
Washington	..	13·5	....	13·25	....	—·25

According to Mr. Schott, the horizontal force at Washington has been steadily increasing since 1853·5. From observations made since 1842·5, he finds that the value of this element may be represented by the formula

$$X=4·270+0·00084(t-1855·0)+0·000248(t-1855·0)^2.$$

For the present epoch the calculated value is 4.4292. My determinations gave 4.3608, in close accordance with Mr. Schott's observation made on June 15, 1878, of 4.366. The difference between the observed and computed values affords further evidence of the fact pointed out by Mr. Schott, that the secular changes in the neighbourhood of Washington are of a mixed progressive, and periodic character. The divergences exhibited both in this case and in that of the dip, further show how very unsafe it is to employ numerical formulæ of this kind beyond the limits of the time within which the observations upon which they are based are comprised.

Declination.

The unifilar magnetometer was provided with a mirror and horizontal telescope in accordance with the plan first proposed by Dr. Lloyd in the "Proceedings of the Royal Irish Academy" for 1858; hence the observations could be carried out in the manner described by Mr. Welsh in the "Admiralty Manual of Scientific Inquiry."

As a rule, six readings of the position of the magnet were taken; three of these were with the scale erect and three with the scale inverted: at Cheyenne, however, owing to lack of time, only four observations were possible.

Care was always taken that the transit-mirror was in adjustment before commencing the observations. The operation of adjustment for collimation-error was greatly facilitated by a neat contrivance which Dr. Balfour Stewart had caused to be introduced in the original construction of the instrument. In order to eliminate any error which might arise from the plane of the mirror not being parallel to its axis, the observations were always made first with the mirror in its normal position and then after reversal on its bearings. Care, too, was always taken to remove, as far as practicable, all torsion from the suspending thread. When time permitted, the magnet was replaced by a torsion-plummet of equal weight, the position of which was noted after an interval of an hour or so, a suitable correction being applied to the original observation if it were found that any torsion still remained in the thread.

As the correct determination of the sun's azimuth was mainly dependent upon an accurate knowledge of local time, every opportunity was taken to ascertain the errors and rates of the chronometers employed. In order to guard against the possible accidents of travel over a country so rough and difficult as that of many parts of Western America, I provided myself with three of these instruments. That lent to me by Dr. Stewart was a large-sized marine chronometer, by Frodsham, No. 4,066; in addition, I hired a pocket instrument from the same makers, No. 5,674, which had behaved well as a "hack" chronometer for some months previously: this was always carried

horizontally in its case and guard-box. For the third instrument I was indebted to Mr. George Salt, of Saltaire, who is well-known for his horological skill and knowledge; it was a remarkably well-finished instrument by Kuhlberg, No. 2,918, and was specially compensated for fluctuations of temperature. The Owens College instrument, however, went so well throughout the entire journey that I used it exclusively, relying on the others mainly for comparisons. At several of the stations, viz., at Ogden, Chicago, Allegheny, and Washington I was able, thanks to the Directors of the observatories at those places, to make comparisons with standard instruments; at La Junta the errors and rates were furnished to me by Professor Hall; on other occasions I obtained the time from Dr. Schuster's observations.

Table V.

Station.	Date.	Error on G. M. T.	Daily rate.	Remarks.
Leeds.....	May 21 '04	m. s. 1 48·0 slow	s.	Comparisons with Post Office 1 p.m. time signal. Comparisons with P. O. time signal and Frodsham 5,674.
"	June 3 '04	1 30·0 "	+1·38	
"	" 9 '04	1 23·8 "	+1·03	
"	" 14 '09	1 18·9 "	+0·97	
"	" 22 '15	1 09·3 "	+1·19	
"	" 26 '47	1 04·4 "	+1·14	
S.S. "Germanic"	July 4 '04	0 57·0 "	+0·99	Time gun at Liver- pool.
"	" 12 '26	0 49·3 "	+0·94	Ship's chronometer Bassett 555.
New York.....	" 20 '31	0 40·3 "	+1·11	Negus standard clock.
La Junta.....	" 25 '17	0 39·7 "	+2·30 +2·36	Comparison with Negus 1,340. Ob- servations fur- nished by Prof. Asaph Hall.
"	" 27 '43	0 34·5 "		
"	" 30	0 27·9 "		
Manitou	Aug. 4 to 6		+2·55	Sextant observa- tions by Dr. Schuster.
Denver	" 8 '29	0 05·7 "	+3·00	
Salt Lake City	" 17 '31	0 33·1 fast		
Ogden	" 23 '67	0 49·6 "	+2·59	Comparison with Negus 1,481 by Prof. Truman Safford.
"	" 24 '69	0 52·1 "	+2·50	
Green River ...	" 26 '29	0 58·4 "	+3·50	Sextant observa- tions by Dr. Schuster.
Grand Island ..	" 28 '28	1 10·8 "		
Council Bluffs .	" 30 '27	1 17·8 "		
Chicago.....	Sept. 1 '69	1 24·4 "	+2·73	Comparison with observatory clock by Prof. Colbert.
"	" 2 '67	1 27·0 "	+2·64	
Allegheny	" 5 '46	1 34·0 "	+2·59	
Washington ...	" 7 '11	1 38·3 "	+2·60	Naval observatory clock, Professor Harkness.

Table V shows the error and rate of chronometer Frodsham 4066, during the course of the journey.

Comparative observations were made at Kew before and after the survey between the unifilar employed in the regular monthly determinations at that observatory and the Owens College instruments, with the following results :—

				Declination.
Kew Declinometer	..	..	May 29, 1878.	19° 13' 36" W.
"	"	..	" 30, "	19 17 44
Owens College Declinometer.	..	..	June 7, "	19 12 03
Kew Declinometer	..	..	Sept. 25, "	19 12 10
"	"	..	" 26, "	19 13 33
Owens College Declinometer.	..	..	Oct. 3, "	19 14 01

The observations for the determination of the astronomical meridian at the several stations are given in Table VI.

Table VI.

Station.	Date.	Local apparent time of passage of ☉ centre.	☉ Circle reading.	☉ Bearing.	Meridian reading of circle.
		h. m. s.			
New Haven..	July 18	7 44 24·6 A.M.	30 06 35	90 04 50 E.	300 01 45
La Junta ..	" 29	5 40 54·4 P.M.	203 10 42·5	77 48 22 W.	280 03 01
Denver ..	Aug. 8	9 23 00·2 A.M.	37 44 22	113 18 13 E.	284 26 09
Cheyenne ..	" 10	11 15 38·3 "	10 55 22·5	156 11 16 "	214 44 16
Salt Lake City	" 15	10 33 12·8 "	247 00 10	138 27 17 "	288 32 53
Green River	" 26	9 00 14·9 "	27 08 43	115 09 23 "	271 59 20
Grand Island	" 28	10 11 12·0 "	76 13 46	134 46 10 "	301 27 36
Council Bluffs	" 30	7 37 12·8 "	45 26 56	99 27 40 "	305 59 16
Chicago ..	Sept. 2	4 10 39·0 P.M.	193 11 46	102 56 00 W.	296 07 46
Allegheny ..	" 5	4 28 49·3 "	20 18 38	99 58 11 "	120 16 49
"	" "	.. ..	.. ..	.. ..	120 22 37*
Washington	" 8	.. ..	.. ..	.. ..	115 18 37*

* Observatory fixed marks.

The corresponding azimuthal readings of the magnet are contained in Table VIa.

Table VIA.

Station.	Date.	Time.		Circle reading.	Declination, correct for torsion.
		h. m.	h. m.		
New Haven	July 18	8 22—	8 47 A.M.	291 20 38	8 40 34 W.
La Junta	" "	6 11—	6 30 P.M.	291 23 07	8 41 55 "
Denver	" 29	4 55—	5 20 "	294 06 56	14 03 55 E.
Cheyenne	Aug. 8	12 17—	12 34 "	299 08 57	14 43 25 "
Salt Lake City . . .	" 10	10 41—	10 44 A.M.	230 17 27	15 33 11 "
Green River	" 15	8 22—	8 40 "	305 20 59	16 48 06 "
Grand Island	" 26	7 41—	8 03 "	288 57 09	16 57 49 "
Council Bluffs . . .	" 28	10 35—	10 53 "	314 19 15	12 51 39 "
Chicago	" 30	7 00—	7 19 "	316 38 58	10 39 42 "
Allegheny	Sept. 2	10 27—	10 45 "	300 40 51	4 33 05 "
"	" 5	10 26—	10 48 "	117 59 51	2 22 46 W.
"	" 5	4 52—	5 08 "	117 49 44	2 20 24 "
Washington	" 8	10 08—	10 33 "	111 36 20	3 42 51 "

I have not attempted to correct these results for diurnal range. Accurate observations of daily change have been made at Philadelphia, Washington, and Key West in Florida, and on the assumption that the range of the daily variation is inversely proportional to the horizontal force, the data derived from these observations may perhaps be considered as fairly applicable to any place in the United States. But such corrections are at best very unsatisfactory, as the epochs of the extreme positions are subject to very great fluctuations on account of disturbances: these are usually most prevalent at about the time at which my observations were made, viz., August and September. The magnet, however, was always quiet during the time of observation; hence the correction due to diurnal range would seldom exceed 3' or 4'.

Observations of declination have been made in the district of Columbia, in which Washington is situated, from as far back as 1792. These have been collected and discussed by Mr. Schott in the memoir above referred to, and represented by him by the formula—

$$(I.) \quad D = 1^{\circ}.79 + 1^{\circ}.90 \sin (1.5n - 24^{\circ}.1),$$

in which n is the number of years since 1830, and D the declination, + when west, expressed in degrees.

The annual variation v was given by the formula—

$$(II.) \quad v = 2'.985 \sin (1.5n + 66^{\circ}).$$

The preceding formula gives the value of the declination for 1870 as $2^{\circ} 54'$, and for 1880 as $3^{\circ} 16'$. The observed declination, however, already considerably exceeds the latter value. Mr. Schott informs me that an observation made on June 15, 1878, gave $3^{\circ} 47'$; my own

determination on September 8, 1878, was $3^{\circ} 42' 85''$ (uncorrected for diurnal range).

In a later publication "On the Secular Change of the Magnetic Declination in the United States and other parts of North America" (United States Coast Survey Report for 1874, Appendix No. 8), Mr. Schott adopts the formula

$$D = 1^{\circ} 79' + 1^{\circ} 90' \sin (1.5m + 5^{\circ} 9'),$$

where m is the number of years and fraction of a year since 1850; but this expression also affords lower values than those actually observed. The value for 1880, for example, is given as $3^{\circ} 15' 6''$, and for 1870 as $2^{\circ} 54'$. Mr. Schott has also discussed (*loc. cit.*) the various observations made at New Haven, Connecticut, since 1761, and has represented them by the expression

$$D = +7.83 + 3.16 \sin (1.4m - 21^{\circ} 6'),$$

where m has the same signification as in the last formula. The annual change is at present about $4' 3''$. This would give for 1878.6 the value $8^{\circ} 45'$, which agrees very closely with that actually observed.

Sir Edward Sabine's collections afford the following data for further comparison :—

	Date.	Declination.		Date.	Declination.	Diff. of epoch. Years.	Yearly Change.
Salt Lake City	.. 1850	$15^{\circ} 34' \text{ E.}$		1878.7	$16^{\circ} 48' \text{ E.}$	28.7	-2.6
Pittsburg	.. 1840.5	$0^{\circ} 08' \text{ W.}$	„		$2^{\circ} 21' \text{ W.}$	38.2	$+3.5$
„	.. 1845.5	$0^{\circ} 33' \text{ W.}$	„		$2^{\circ} 21' \text{ W.}$	33.2	$+3.3$

At Salt Lake City I was informed by Mr. Orson Pratt, who led the first band of Mormons into Utah, that he had determined the magnetic declination on what is now the site of the Mormon Tabernacle, and he was so good as to afford me the following extract from his journal :—
 "July 30, 1847. I took several observations during the day of the sun's azimuths and altitudes, and by means of seven calculations I ascertained the variation of the magnetic needle to be $15^{\circ} 47' 23'' \text{ E.}$ Instruments, sextant and ordinary azimuth compass."

In concluding, I wish to tender my thanks to the various officials connected with the public service in America with whom I came in contact, for the prompt and courteous manner with which all our requirements relating to the magnetic work were met. To General Smith, commanding at Fort Lyon, in Colorado, we were indebted for the loan of a tent which was placed at our disposal during the whole of our journey; Rear-Admiral Rodgers, the Director of the United States Naval Observatory at Washington, furnished us with maps and letters, and procured us special facilities from certain of the railroad companies, and otherwise showed his interest in the work.

Addendum. April 26, 1879. Received April 28, 1879.

Since sending in the foregoing communication to the Society, I have received the following letter from Mr. C. A. Schott, of the United States Coast Survey Department, respecting the inadequacy of the formula published in the Report of 1870, as representing the values of the magnetic elements at the present time.

It will be noticed that Mr. Schott confirms my observations on this point; and by permission of the Superintendent of the Survey, he sends amended formula for dip, declination and horizontal force which represent with sufficient accuracy both series of observations, viz., his made in June, and mine made in September, 1878.

United States Coast Survey Office,
Washington, March 28th, 1879.

MY DEAR SIR,

I hasten to reply to yours of March 13, respecting magnetic observations in this city. The formulæ in the 1870 Report undoubtedly fail to represent adequately our late observations, a contingency which was referred to in the concluding paragraph of that report: "They should not be used much beyond the time for which they are supported by observations." There is nothing unusual going on in the behaviour of terrestrial magnetism in this locality, and the dip and intensity formulæ may be easily amended to represent our observations, but in regard to the declination there is a disturbing element introduced, viz.: the *change of station* in 1876, which developed a local difference of 20' as near as I can judge; whether the old or new place is the more normal one I cannot say. There is apparently no difference in dip and intensity. Considering the dissimilarity of the instruments used our observations agree well, indeed they accord within the daily variations of the magnetic force. By permission of the Superintendent of the Survey, I enclose the latest formulæ for declination, dip, and intensity in this place, as well as my observations of last year; they are:—

The magnetic dip observed at Washington between 1839 and 1879 can be represented by the formula—

$$I = 71^{\circ} \cdot 335 - 0 \cdot 000229 (t - 1855 \cdot 0) - 0 \cdot 000640 (t - 1855 \cdot 0)^2 \\ - 0 \cdot 0000140 (t - 1855 \cdot 0)^3,$$

which will leave no greater differences than those given by the old formula. (Report of 1870.) The magnetic horizontal intensity observed between 1842 and 1879 is represented by

$$H = 4 \cdot 270 + 0 \cdot 00084 (t - 1855 \cdot 0) + 0 \cdot 000130 (t - 1855 \cdot 0)^2,$$

which will leave differences of about the same character as those given by the old formula.

The very nature of these functions precludes them from answering for any length of time, and as soon as the case becomes ripe, I shall substitute harmonic functions.

The following is an improved formula for the declination at Washington, prepared for a new edition of the paper in the 1874 Report :

$$D = +2^{\circ}19 + 2^{\circ}22 \sin (1\cdot4m - 6^{\circ}6),$$

it represents the observations between 1792 and 1879; $m = t - 1850\cdot0$.

These observations are difficult to manage on account of considerable local deflection in this vicinity produced by iron (bog-ore) which in many places crops out to the surface.

Our observations compare as follows :

In latitude $38^{\circ} 53' 2$: longitude $77^{\circ} 00' 4$.

		Declin.		Dip.		Hor. Inten.
June 14, 15, 17.	C. A. Schott	.. $3^{\circ} 47'$	..	$70^{\circ} 49'$	..	4.366
Sept. 8, 1878.	T. E. Thorpe	.. $3^{\circ} 43'$	..	$70^{\circ} 47'$	..	4.361

Yours very truly,

CHAS. A. SCHOTT.

Dr. T. E. THORPE,

Yorkshire College, Leeds, England.